SECTION 98

MISSION 119 PASSIVE MICROWAVE RESULTS

by

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INTRODUCTION

Passive microwave measurements of the sea surface for the purpose of determining surface wind speeds were made from the NP3A aircraft (NASA-927). Observations were made at frequencies of 1.4, 10.6, and 31.4 GHz during NASA Mission 119 undertaken off Bermuda in the vicinity of Argus Island sea tower during January 1970.

The microwave brightness temperature dependence on sea surface wind speeds arises from two effects (1). The first effect results from increasing roughness of the compact water surface with wind speed and the second effect from the increasing coverage of white caps and sea foam with increasing wind speed. Although both are roughness effects, the first is referred to as the surface roughness effect and the second as the foam effect.

Passive microwave observations from Argus Island ocean tower (1) have shown that the surface roughness effect, besides being dependent on the wind speed, is also dependent on observational frequency, increasing with increasing frequency. The surface roughness effect is closely coupled to the local wind fields, rapidly responding to changes in local wind, and appears relatively insensitive to the energy content of the low frequency gravity waves. In addition the surface roughness effect is a function of the angle of observation and the polarization of the radiation received. The wind speed dependence is greatest at larger incidence angles of horizontal polarization. The roughness effect appears to be dominant for wind speeds less than 30 to 40 knots (2).

The sea foam effect is expected to be dominant at the higher wind speeds (> 30 knots) when the surface is covered with a high percentage of sea foam. Unfortunately the percentage of foam-covered surface as a function of wind speed is not a unique relationship but is greatly influenced by the fetch and duration of the wind, the air-sea temperature differences and the salinity (3). The microwave brightness temperature of sea foam is known to be on the order of 100°K higher than the radiometric temperature of the surrounding sea water (1), (2), (4), (5), (6), (7). The sea foam effect, as compared to the surface roughness effect, appears to be relatively independent of polarization and incidence angle. It is also expected that the brightness temperature of foam should decrease with decreasing observational frequency for foam layers having thicknesses of only a fraction of the observational wavelength. The data available at present is, however, insufficient to describe in detail the microwave characteristics of foam as a function of frequency, polarization, and incidence angle.

Most airborne passive microwave measurements of sea surface conditions have been performed by the NASA/GSFC 19.4 GHz scanning radiometer which is a single polarization device that scans in incidence angle ± 50 degrees (5), (6), (7), (8). A lesser amount of airborne measurements have been made either with fixed angle or calibration limited systems or were made over a limited range of sea surface conditions (4), (6), (9). Further airborne multifrequency passive microwave measurements are required to unequivocally demonstrate that an airborne radiometer system can indeed provide radiometric brightness temperature changes that can be quantitatively correlated with wind induced sea surface roughness and foam effects.

The ability of airborne radiometers to quantitatively and accurately measure surface wind fields over a wide range of wind and sea conditions may best be tested by using a multifrequency airborne system having dual polarization, and observing at multiple look angles over a wide variety of sea surface conditions. Accordingly, Mission 119 was conducted using the NASA NP3A multifrequency radiometers in a locale expected to provide the required categories of sea surface variations.

DESCRIPTION OF EQUIPMENT

The radiometers, mounted behind the radome in the nose of the P3A, are conventional Dicke-type radiometers using crystal mixers and klystron local oscillators. Argon noise generators are used for inflight calibrations for the 10.6 and 31.4 GHz systems, and a solid-state noise generator is used for the 1.42 GHz radiometer. The basic system parameters are listed in the following table. A full description of the systems operation, calibration, data collection, and recording is contained in LEC/HASD Technical Report 649D.21.017C (10).

TABLE

Frequency (GHz)	ΔT_{rms}* (°K)	Half-Power Beam Width (Degrees)	Typical Radome Loss Value (dB)	Antenna Loss (dB)
1.4	1.6	16	0.30	2.10
10.6	1.0	5	0.45	0.45
31.4	0.8	5	1.20	0.25

*referenced to outside of the radome for a one-second time constant.

GROUND TRUTH

Primary ground truth was recorded at the Argus Island tower and consisted of wind speed, wind direction, significant wave height, and maximum wave height as provided by D. B. Ross of NAVOCEANO (11). All airborne data used in analysis were runs starting or stopping within the vicinity of the tower. The wind speeds correlated with the airborne measurements ranged from six to thirty-six knots and were obtained by averaging over ten second intervals the wind speed data recorded at a height of 43.3 meters above the sea surface. The sea temperature measured by the PRT-5 infrared radiometer during the measurements was 290°K ± 1°K; the salinity has been measured at 35 o/oo ± 1 o/oo.

DATA COLLECTION AND PROBLEMS

During the nine flights, forty-five data sets were collected. A data set consisted of either horizontal or vertical polarization observations at nine incidence angles between nadir and 80 degrees. Evidences of long and short term instabilities in the radiometer systems necessitated using more than thirty percent of the flight time for inflight calibrations. Large, obvious instabilities appearing during and after operations at high altitudes resulted in all the data (40 %) taken above 1500 feet to be excluded from analysis.

Absence of identification data on magnetic tape recordings prevented a timely, efficient reduction of all aircraft tape recorded data. The main radiometer output data was obtained from manual reduction of the on-board analog strip charts although supplementary data required in the reduction program was derived from the magnetic tape. The raw data, plotted as a function of look angle, was used to evaluate the stability of each set and to rectify obvious discrepancies in the radome loss values that had been provided by MSC as a function of frequency, incidence angle, and polarization. The uncertainties in radome losses and instabilities of the system precluded the derivation of accurate absolute brightness temperatures. However, the system is considered capable of providing useful relative measurements for comparison between frequencies and for comparison with the Argus Island tower based measurements.

1.4 GHZ RADIOMETER

Large day-to-day shifts were observed in the radiometer output levels such as might be caused by a variable lossy element in the antenna line or to a varying inflight calibration temperature. A study of the performance of the inflight reference generator during the mission dismissed this as a source of trouble. Several months after the mission, the 1.4 GHz phased array antenna exhibited a loss greater than 3 dB, was dismantled, found to have defective elements, and was refurbished. Consequently, the 1.4 GHz results cannot be presented until a valid level adjustment, if one is possible, can be performed upon the data.

10.6 GHZ AND 31.4 GHZ RADIOMETERS

The data presented here is the average for a specific wind speed on a given day. The raw data was converted to antenna temperatures by using the inflight calibrations, the temperatures of the Dicke-load, waveguide, antenna, and radome, and the loss values of the radome and waveguides. Normally, data at nadir is independent of polarization and may simply be averaged together; however, the radome losses were different for each polarization and had different errors. Consequently, a bias level existed between the data collected at nadir horizontal polarization and nadir vertical polarization. The two polarization components were averaged together after a multiplicative correction factor, based on the calm sea data, was applied to all nadir data.

A "first-order" correction for reflected sky radiation was made by using a calculated emissivity to obtain a sea reflectivity and assuming specular reflection of the sky radiation

$$[1 - e(\theta)] \, [1 - e^{\tau \sec \theta}] \, T_{sky} \quad .$$

$e(\theta)$ = calculated emissivity as a function of angle and polarization for smooth sea water at 18°C.

τ = optical depth was determined from an NRL clean air atmospheric model which required an absolute humidity input which in turn was determined from aircraft measurements of relative humidity and temperature recorded at 200 to 500 feet altitude.

θ = incidence angle of observation.

T_o = temperature of atmosphere ± 295°K.

This correction removes the bulk of the reflected sky radiation. However, the corrected data still contains a small residual reflected sky component which is dependent upon the atmospheric opacity and sea surface roughness (1).

As all the antennas have high beam efficiencies (90%), a correction for the antenna beam pattern was made by using the beam efficiency factor of 0.9 for all three frequencies and making a constant correction for the sidelobes and backlobes contributions, independent of angle. No further correction or data treatment was considered justified in light of the operational instabilities and unknowns in the system parameters. The relative errors in the derived brightness temperatures are estimated to be ± 3°K.

RESULTS

Figure 1 presents the nadir and 50 degree incidence angle observations for both polarizations at 10.6 and 31.4 GHz. The solid lines are linear least-square solutions fitted to the data. A wind speed dependence is apparent in all of the measurements. However the dependence is at least twice as large at 50 degrees horizontal polarization than at nadir or 50 degrees vertical polarization. The wind speed sensitivity is comparable, within the error of measurement, at nadir and at 50 degrees vertical polarization. In addition the wind speed dependence is larger at 31.4 GHz than at 10.6 GHz.

As mentioned previously, the radiometric temperature contributions associated with the foam effect are relatively insensitive to polarization and incidence angle; whereas surface roughness effects are greatest for the horizontal component at large incidence angles (2). The larger wind speed dependence at 50 degrees horizontal polarization is attributed to a combination of surface roughness and sea foam effects. Whereas, the smaller dependence for vertical polarization and at nadir look angles is considered to be due principally to sea foam.

The presence of such a relatively low percentage of sea foam suggested by the data was substantiated by the ground truth; even for the 33 to 36 knot wind case, Williams (12) estimated a foam coverage of five and a half percent. The potential of using the 50 degree horizontal polarization (Ka band) as an indicator of surface wind fields is demonstrated here even on a relative measurement basis.

OBSERVATIONAL-FREQUENCY DEPENDENCE OF THE SURFACE ROUGHNESS EFFECT

It is desirable to combine both the Argus Island tower measurements (1) at 1.4, 8.4, and 19.3 GHz and the aircraft measurements at 10.6 and 31.4 GHz for analysis of the wind speed dependence of the surface roughness effect on observational frequency. In order to effect this comparison, the sea foam contributions must be removed from the aircraft measurements. The aircraft data may be modified to remove the foam effects by adopting the 5.5% foam coverage value reported by Williams (12) for 33 to 36 knot winds. A value of 100°K temperature increase for 100% foam coverage has been reported (2), (5). Assuming a linear approximation for percentage of foam versus increase in brightness temperature, a foam-induced contribution of 0.16°K/knot will result using a 5.5% foam coverage over a 35 knot range. Note that the magnitude of this foam contribution is consistent, within the stated error, with the wind speed dependence observed at nadir and 50 degrees for vertical polarization at both the 10.6 GHz and 31.4 GHz. Such a modification applied to the nadir and 50 degree vertical polarization data virtually removes the wind speed dependence as would be expected if the dependence were due primarily to foam effects. Furthermore, subtracting this foam contribution from the 50 degree horizontal polarization data yields results which indicate a sensitivity due to the surface roughness effect alone that is 1.8 times greater at 31.4 GHz than at 10.6 GHz.

The aircraft results with the sea foam contribution removed may be compared with the results from Argus Island tower (1) to examine the frequency dependence of the surface roughness effect. The wind speed dependence at 50 degrees incidence angle for horizontal polarization is presented as a function of frequency in figure 2. The present results are indicated by x's and the Argus Island results at 1.4, 8.4, and 19.4 GHz are represented by O's. The aircraft results agree well with the tower measurements and indicate a wind speed dependence which increases with frequency. Although the data is well represented by the dotted line, which indicates a wind speed dependence proportional to the square root of the frequency, we have no compelling explanation for such a relationship.

CONCLUSIONS

Mission 119 airborne passive microwave measurements definitely demonstrated that the microwave brightness temperature of the sea is significantly dependent on the surface wind fields. The measurements show that the wind speed dependence for the 50 degree incidence angle horizontal polarization component is greater than the dependence either for the vertically polarized component at 50 degrees incidence angle or for nadir. Further, the greater wind speed dependence for the 31.4 GHz than for the 10.6 GHz radiometers demonstrates, in agreement with the Argus Tower results, that the sensitivity to wind speed increases with increasing observational frequency.

All of the increase of brightness temperature with wind speed at nadir and at 50 degree vertical polarization was readily accounted for in total by the foam effects. The horizontal polarization component at 50 degrees incidence angle had a major wind-speed dependent residual component even after removal of the foam effect. This residual is due to the surface roughness effect and is also in agreement with the Argus Tower measurements. Indeed, these airborne measurements support the contention that there are two effects, roughness and foam, that are responsible for the dependence of the microwave brightness temperature on surface wind speeds.

These measurements, along with the Argus Tower measurements, indicate the significant potential of using passive microwave radiometers as a means of remotely sensing wind from calm to 50 knots and above. Because foam effects are relatively small below 25 knots, observations at large incidence angles must be made to take advantage of the roughness effect predominant at the lower wind speeds.

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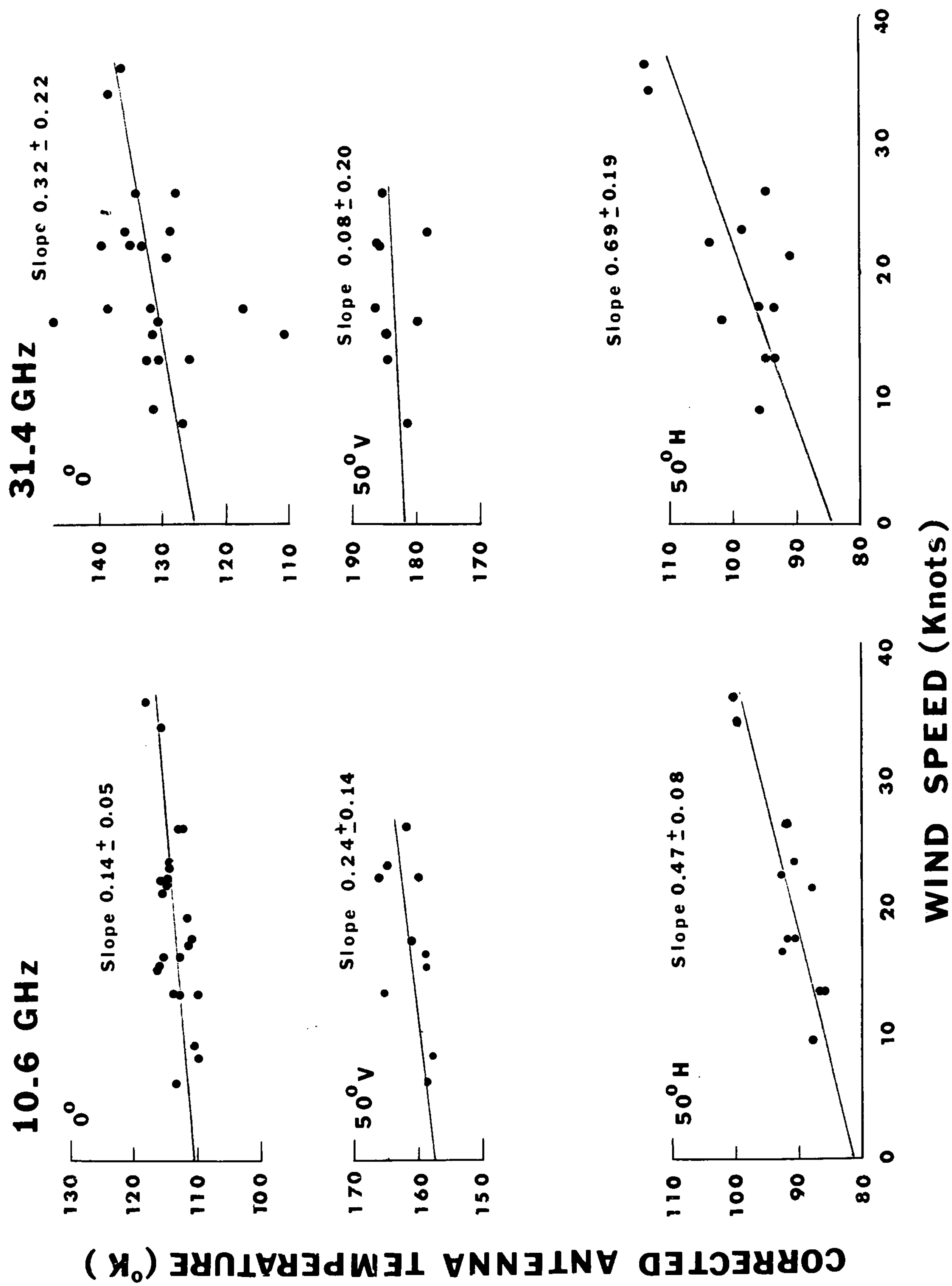
10.6 GHz
31.4 GHz
0°
50°V
50°H
Slope 0.14 ± 0.05
Slope 0.24 ± 0.14
Slope 0.47 ± 0.08
Slope 0.32 ± 0.22
Slope 0.08 ± 0.20
Slope 0.69 ± 0.19
CORRECTED ANTENNA TEMPERATURE (°K)
WIND SPEED (Knots)

Figure 1

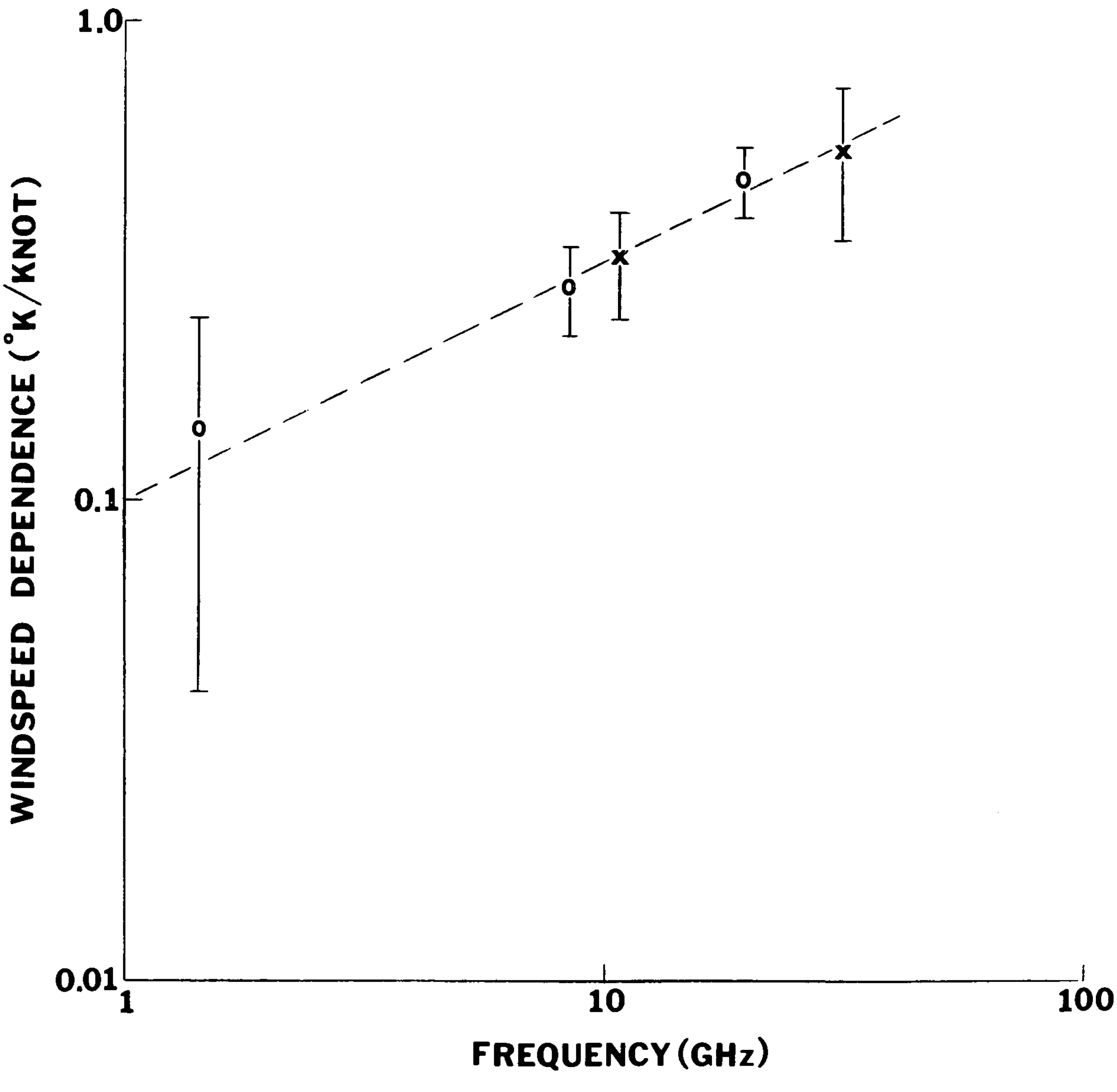

Figure 2